The Literature Review of Wind Turbine Fault Early Warning Technology

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Abstract

In recent years, wind energy has played an increasingly important role as a clean energy source for improving China's energy structure, which has developed rapidly. Although the design and manufacture of wind turbines have been gradually improved which due to the complex and variable operating loads and poor working conditions, the failure rate of wind turbines is still high, which poses a huge challenge to its operation and maintenance. Therefore, research and popularization of wind turbine condition monitoring and fault diagnosis technology has important practical significance for improving the operational safety and reliability of wind power equipment. Fault diagnosis technology is the key to ensure the efficiency of wind farm operation and reduce the operating cost of wind farms. In this paper, the existing fault diagnosis methods for wind turbines are combined with the fault diagnosis system. The existing fault diagnosis methods are classified again. The basic ideas, applicable conditions, application scope, advantages and disadvantages of these methods are pointed out, and the main possible development direction of unit fault diagnosis technology in the future is discussed.

Keywords

Wind turbine, fault warning, support vector machine, neural network.

1. Introduction

With the continuous development of the world economy, the global power consumption is increasing, the problem of the gradual depletion of non-renewable energy has become more and more serious, and the environmental problems brought about by the burning of fossil energy have become an important factor threatening the normal life of human beings. As a result, renewable energy such as wind, solar and hydropower has developed rapidly. Among them, wind energy has become an important development direction of global renewable energy with its rich reserves and abundant sources[1].

At present, wind power generation technology is relatively mature and low in cost, and it is the most renewable energy source with the fastest development prospects. As wind farms are being built more and more, wind turbines are heavily put into operation, and related problems are coming one after another. Wind farms are generally located in remote areas, the working environment is complex and the wind turbines have a high probability of failure. If the key components of the unit fail, the equipment will be damaged, and even the unit will be shut down, resulting in huge economic losses[2] . According to statistics, the component with the highest probability of failure of a wind turbine is the gearbox. The gearbox is small and at high altitude, and if it fails, maintenance becomes extremely difficult. According to statistics, in the failure of wind turbines, more than 60% are gearbox failures[3]. Therefore, wind turbine gearbox condition monitoring, fault diagnosis and intelligent maintenance technology are gradually becoming new industry growth points. Using on-line monitoring technology to perform continuous monitoring of various operating parameters of the wind turbine, obtain various types of information that can reflect the operating status of the unit, and combine certain diagnostic reasoning methods to determine whether the operating conditions of the equipment are normal, and arrange a reasonable maintenance plan accordingly. Not only can the safety performance of the unit be greatly improved, but also the operating cost of the wind farm can be effectively reduced.

Since the concept of fault diagnosis technology has been proposed, many effective state monitoring and fault diagnosis methods have been produced, but the state monitoring and fault diagnosis technology of wind turbines in its infancy, and most of the existing research results are directed to wind turbines. Research on blades, gearboxes and generators[4]. Based on the summary of the existing research results, this paper analyzes the fault diagnosis method of the existing wind turbine gearbox and combines with the fault diagnosis system. The fault diagnosis of the wind turbine gearbox is described in detail. The research status quo explores the development trend of wind turbine fault diagnosis technology combined with the current situation.

2. Research status

In the early 1980s, the United States and Denmark began research on wind turbines. Wind power technologies in Germany and Denmark developed rapidly, far surpassing other countries. In recent years, Spain has come to the forefront, surpassing Denmark, and its installed capacity ranks second in Europe. China's wind power technology started late, but its development speed is very fast. At present, China has become a major renewable energy country. With the continuous development and maturity of wind power technology, more and more wind farms are gradually being built, and a large number of wind turbines are put into operation. Various fault problems have also come along, so they must be effective. Fault diagnosis to ensure long-term stable operation of wind turbines[5-9].

There are many literatures on traditional gearbox fault diagnosis technology, but the fault diagnosis of wind turbine gearboxes, especially early fault diagnosis, has only begun in recent years, and there are few research literatures at home and abroad. The fault diagnosis technology is a technology that monitors its state when the device is in use, uses various test methods to judge whether the device state is normal, finds an abnormal state and quickly finds the cause of the fault, and estimates the trend of the fault. Fault diagnosis is a rapidly developing interdisciplinary subject, including electronics, computer, testing, pattern recognition, artificial intelligence and information processing. It is also a science that combines theory and application[6].

In recent years, artificial intelligence algorithms have been gradually applied to fault diagnosis with the rapid development, which making fault diagnosis technology unprecedentedly developed, and the accuracy of fault diagnosis is also increasing. During this period, many intelligent fault diagnosis methods have been produced. Many new theories and new methods have been introduced into the field of fault diagnosis, such as rough set theory, fuzzy set theory[10,11], expert systems, neural networks and support vector machines[12-14] and the integrated cross-application of these methods and theories[15-17], etc.

2.1 Expert System

The Expert System (ES) is a computer program system that simulates human expert reasoning methods to solve domain problems. At present, the expert system has been more maturely applied to power system fault diagnosis. Its typical application express the protection logic of the protection and circuit breaker and the diagnostic experience of the operating personnel, which form knowledge base and then reason the knowledge base based on the alarm information to get the diagnosis. In expert system diagnostic methods, the action logic and the relationship between protection and circuit breakers can be represented by more intuitive, modular rules and allowed to be added, deleted or modified to ensure the real-time and effectiveness of the diagnostic system, while it can give conclusions that conform to human language habits and have corresponding explanatory powers. However, it also has some shortcomings in practical applications. It has poor fault tolerance and lack of effective methods to identify error information. Knowledge acquisition and completeness verification are difficult. No learning ability and the maintenance of large expert systems is also very difficult.

2.2 Artificial Neural Network

Artificial Neural Network (ANN) is an important artificial intelligence technology that simulates the process of transmitting and processing information in the human nervous system. The biggest feature of artificial neural networks is the use of neurons and their directed weighted connections to implicitly deal with the problem. Artificial neural networks have been widely used in fault diagnosis. The application of ANN in power system fault diagnosis is mainly fault location and fault type identification. It has good robustness, strong learning ability, no need to construct inference engine, and fast inference speed. At present, ANN also has some problems in application. How to obtain a complete knowledge base in large-scale systems and it is difficult to ensure the rapid convergence of ANN training and avoid falling into local minimum. It also lack of ability to explain its own behavior and output results.

2.3 Bayesian Network

Bayesian Network (BN) is a kind of uncertainty processing model that simulates causality in human reasoning. Its network topology is a directed acyclic graph whose nodes are identified by random variables or propositions. Propositions or variables that are considered to be directly related are connected by arcs, and probabilistic events can be reasoned according to known network topology models. Bayesian network theory has a strict foundation of probability theory.

It has great advantages for solving fault diagnosis caused by uncertain factors of complex systems. It is one of the most effective theoretical models in the field of uncertain knowledge representation and reasoning. Applying Bayesian network technology to power system fault diagnosis can make up for the uncertainty of diagnostic technology and data fault tolerance. The Bayesian network method can effectively improve the diagnostic accuracy and speed, and is suitable for the complexity and uncertainty of large-scale fault information. The Bayesian network is gradually applied to the fault diagnosis of hydropower units, transformer fault diagnosis and state estimation of overhead transmission lines, and has achieved good results. However, this method has the following disadvantages. It is difficult to acquire knowledge and how to realize fault diagnosis under information fusion and realize automatic modeling under complex power grid.

2.4 Rough Set

The Rough Set (RS) theory is a mathematical tool for dealing with uncertain and inexacting problems. It does not need to provide any priori information beyond the data set to be solved when solving the problem, while maintaining the classification ability. Under the premise, the decision-making or classification rules of the problem are derived through knowledge reduction. It can effectively analyze and deal with incomplete data such as inaccuracy, inconsistency and incompleteness, and discover hidden knowledge and reveal potential laws. Fault diagnosis using rough set theory can deal with the situation of incomplete information and redundant information. At the same time, the method also needs improvement. The acquisition of the diagnostic rules of the rough set method depends on the training sample set of various fault conditions under the condition attribute set. When the alarm information of the missing or error is the key signal, the diagnosis result will be affected. When the power grid is complex and large, it will lead to a larger scale of decision tables, which is difficulty in reduction and lower diagnostic speed.

2.5 Fuzzy Set Theory

Fuzzy Set Theory (FT) fuzzifies the classical set theory, which uses the concept of fuzzy membership degree to describe inaccurate and uncertain objects, and introduces fuzzy logic of linguistic variables and approximate reasoning. It is a complete reasoning system with intelligent technology. Fuzzy theory can simulate the approximate reasoning process of human thinking. It is mainly used in the occasion where human experience knowledge plays an important role. It has outstanding advantages in fault tolerance. Therefore, the method based on fuzzy theory is more suitable for fault diagnosis. At the same time, the shortcomings of fuzzy theory are also obvious which includes the maintenance of the rule base is complex. It does not have the ability of self-learning. There still have no effective solution of a large number of incomplete and uncertain information in power system fault diagnosis,.

2.6 Support Vector Machines

Support Vector Machines (SVM) are mainly used for pattern recognition and regression problems. The field of pattern recognition mainly includes face detection, image analysis, text classification and many other aspects. The earliest application of technology to face detection, direct training of non-linear classifiers for face and non-face, and then pattern recognition, training nonlinear classifier wastes storage space, making classification speed slower. Subsequently, another new type of classifier is proposed, which firstly excludes the background part of the image to be recognized by linearity, and then uses the nonlinearity to perform face recognition, which greatly shortens the detection time.

In order to solve the problem of over-learning or under-learning caused by improper selection of characteristic sample parameters and nuclear parameters, the literature combined with wavelet packet and SVM method to diagnose faults of wind turbine converters. Firstly, wavelet packet analysis is used to process DC-side output voltage signals. In order to extract the sensitive spectral feature vector, and then use it as the fault feature sample data to train the fault classification model, and finally get the SVM fault classifier. The intrinsic time-scale decomposition (ITD), least squares (LS) and SVM are used to diagnose the faults of wind turbine bearings. The vibration signal of the roller bearing is taken as the research object. The ITD extracts the fault feature vector and inputs it to the LS-SVM for training to complete the fault identification of the test sample, which effectively improves the fault classification ability of the single SVM method. In order to solve the problem of single-core SVM and parameter optimization, the literature applied the synthetic nuclear support vector machine to the fault diagnosis of wind turbines, which not only improved the stability of classification, but also improved the accuracy of classification. Literature proposed a combination of fast fourier transform (FFT), relative principle component analysis (RPCA) and SVM for wind turbine cascading multilevel inverters. The fault diagnosis method uses FFT to preprocess the original signal to realize data compression and feature extraction. Then RPCA is used for data optimization and dimensionality reduction processing to realize SVM fault classification. This method solves the problem that SVM is not suitable for large sample data.

In general, the small sample and high-dimensional nonlinear classification features of SVM accelerate its application in wind turbine fault diagnosis. But the selection of nuclear parameters and sample parameters of a single SVM and whether the fault samples are complete and representative, which affect the accuracy of fault diagnosis seriously.

3. Conclusion

With the rapid development of high-power wind turbines and grid-connected operation, people have to put higher requirements for their operational reliability and system stability, which will certainly promote the further development of wind turbine condition monitoring, fault diagnosis and intelligent maintenance technology. Based on the research results of wind turbine gearbox fault diagnosis method, this paper summarizes the current mainstream wind turbine fault diagnosis methods and related technologies from qualitative and quantitative perspectives. And from this, any single technology or absolute method can not solve all the fault diagnosis problems of wind turbines. Therefore, the combination of various technical methods and the shortcomings to realize the fault diagnosis of wind turbines will gradually become a hot research topic in the future.

References

[1] Dong Wenting. Intelligent assessment and diagnosis of wind turbine health status based on big data analysis [D]. Donghua University, 2016.

[2] YANG WX, JIANG JS, TAVNER PJ, et al. Monito-ring wind turbine condition by the approach ofempirical mode decomposition[C]. 2008 Interna-tional Conference on Electrical Machines and Syst-ems. Wuhan, China: IEEE, 2008: 736-740.

[3] Global Wind Energy Council .Global Wind Report Annual Market Update 2012[R].2013.

[4] Long Xiafei, Yang Ping, Guo Hongxia, Wu Xiwen.Overview of fault diagnosis methods for large-scale wind turbines[J]. Power grid technology,2017,41(11):3480-3491.

[5] Shao Xiaofei, Ning Yuan, Liu Yaowen, Zhang Huiying. Overview and Prospect of Power System Fault Diagnosis Methods [J]. Industrial Control Computer, 2012, 12.

[6] Zhai Weigang, Li Yongxiang, Sun Yanjun. Review of research status and prospects of power system fault diagnosis [J]. Automation and Instrumentation, 2015, 02.

[7] Amirat, Y M.E.H. Benbouzid, E. Al-Ahmar. A brief status oncondition monitoring and fault diagnosis in wind energy conversion systems [J]. Renewable and Sustainable Energy Reviews, 2009, 13(9): 2629-2636.

[8] E. Echavarria, T.Tpmiyama. Fault diagnosis system for an offshore wind turbine using qualitative physic [C]. EWEC 2008, Brussels, Belgium, 2008.

[9] Baoping Tang, Tao Song, Feng Li, et al. Fault diagnosis for a wind turbine transmission system based on manifold learning and Shannon wavelet support vector machine [J]. Renewable Energy, 2014, 2(62): 1-9.

[10] Wang Junhui, Jia Wei, Tan Bo. Fault Diagnosis of Wind Turbine Gearbox Based on EEMD and Fuzzy C-Means Clustering[J]. Journal of Solar Energy, 2015, 02: 319-324.

[11] Li Zhi, Liu Yibing, Ma Zhiyong, Teng Wei. Adaptive resonance neural network combined with C-means clustering in wind power.

[12] An Xueli, Jiang Dongxiang, Chen Jie, Liu Chao. Fault Diagnosis of Wind Turbine Bearings Based on ITD and LS-SVM[J]. Electric Power Automation Equipment, 2011, v.31; No.20909:10-13.

[13] Li Tao, Tang Mingzhu, Tan Xinxing. Fault Diagnosis of Wind Turbine Gearbox Based on CLSSVM[J]. Renewable Energy, 2015, 02: 232-237.

[14] Liu Ying. Research on the fault diagnosis system of the SVM wind turbine gearbox [D]. North China Electric Power University, 2013.

[15] Xiang Ling, Yan Xiaoan. Fault Diagnosis of Gearbox of EITD Wind Turbine Based on Wavelet Packet[J]. Journal of Power Engineering, 2015, 03:205-212. Application of Fault Diagnosis of Unit Gearbox[J]. Engineering Journal, 2015, 08: 646-651.

[16] Peng Guohua. Development of on-line vibration monitoring system for wind turbine gearbox [D]. Nanjing University of Aeronautics and Astronautics, 2013.

[17] QI Qi. Research and application of data acquisition and monitoring system for wind farm operation [D]. North China Electric Power University, 2014.